Editor: Ron Vetter, University of North Carolina at Wilmington, Mathematical Sciences Dept., 601 South College Rd., Wilmington, NC 28403; voice (910) 962-3671; fax (910) 962-7107; vetter@cms.uncwil.edu.

Internetworked Graphics and the Web

Theresa-Marie Rhyne, Lockheed Martin

Don Brutzman, Naval Postgraduate School

Michael Macedonia, Fraunhofer Center for Research in Computer Graphics

Although the networking and computer graphics fields are considered to be distinct disciplines, they must begin to converge in order to support collaborative exploration and information visualization on the Internet and the World Wide Web. Telecommunication breakthroughs remove bottlenecks and provide new opportunities for interactive 3D graphics across globally interconnected, dissimilar networks. Multicast Backbone (MBone) tools, developed in the networking arena, provide desktop videoconferencing tools for sharing information visualization and virtual reality explorations. The Virtual Reality Modeling Language (VRML), developed in the computer graphics arena, supports the 3D display and fly-through of networked computing resources on the Internet.

The computer graphics community considers VRML to be an interactive tool for exploring content on the Web. The telecommunications community calls it an application on the networking infrastructure. Here we define the concept of Internetworked Graphics to describe the future merger and dependencies of computer graphics applications and the telecommunications networking infrastructure.

The concept of Internetworked Graphics can be examined from six perspectives:

- *Connectivity*: The capacity, bandwidth, protocols, and multicasting capabilities on the networking infrastructure.
- *Content*: Defined in terms of the Web, content encompasses any type of information, dataset, or stream used in the computer graphics environment.
- *Interaction*: Requires minimal latency, a sense of presence, and the ability to both access and modify content.
- *Economics*: Creation of financial mechanisms to support Internet and Web usage as well as online secure money transactions.
- *Applications*: Establish the context for internetworked graphics and determine infrastructure development.
- *Personal aspects*: The sense of wonder associated with information discovery and exploration.

For more information about these six aspects, see the article by Don Brutzman, "Graphics Internetworking: Bottlenecks and Breakthroughs," (*Digital Illusion*, Addison Wesley, 1997, to appear; http://www.stl.nps.navy.mil/~brutzman/breakthroughs.html).

EXPANDING INTO 3D WITH VRML

VRML has already extended the Web to three spatial dimensions. The VRML specification is based on an extended subset of the Silicon Graphics, Inc.'s OpenInventor scene-description language. Key contributions of the initial VRML 1.0 standard (available at http://www.sdsc.edu/vrml/spec.html) were a core set of object-oriented constructs augmented by hypermedia links.

Networking and computer graphics must converge to support collaborative exploration and information visualization on the Web.

VRML 1.0 allowed for scene generation by Web browsers on PCs as well as Unix workstations. The interaction model of 3D VRML browsers is client-server, similar to most other Web browsers. 3D browsers are usually embedded into 2D browsers (such as Netscape's Navigator or Microsoft's Internet Explorer) or launched as helper applications when connecting to a 3D site.

VRML 2.0, released in August 1996 (http://www.sdsc.edu/vrml/spec.html), expands VRML 1.0 to address real-time animation issues on the Web. VRML 2.0 provides local and remote hooks (APIs) to graphical scene description. It enables the simulation of dynamic scene changes by any combination of scripted actions, message passing, user commands, or behavior protocols. In order to scale to many simultaneous users, VRML 2.0 requires peer-to-peer interactions in addition to client-server's query-response model. Here we begin to hit upon one of the bottlenecks of Internetworked Graphics. Future networked VRML scenes will demand significant real-time streaming in addition to client-server interactions.

The development of the next generation of Web software requires effective implementation of these Internetworked Graphics concepts.

Rendering Internetworked Graphics is a matter of human interface technology. VRML primitives provide the raw material for anyone to put together a sophisticated 3D scene that is viewable on any computer platform. VRML 2.0 script connections also enable scene animation, locally and globally. However, the Internet's applications layer does not provide sufficient support for VRML demands about to be made by users and content developers who will start connecting every imaginable geometry to every imaginable information stream. A new protocol is needed to extend the Web into fully interactive 3D large-scale virtual environments. This protocol will need to address the integrated needs of computer graphics content developers with the telecommunications infrastructure.

MBONE FOR VIRTUAL COMMUNICATION

The MBone is one of the Internet's most interesting capabilities (see M.R. Macedonia and D.P. Brutzman, "MBone Provides Audio and Video Across the Internet," *Computer*, Apr. 1994, pp. 30-36). It is used for live audio, live video, and packets such as Distributed Interaction Simulation (DIS) on a global scale.

MBone is a virtual network—it shares the same physical media as the Internet and relies on a network of routers (*mrouters*) that can support multicast. Mrouters are either upgraded commercial routers or dedicated workstations that run modified operating system kernels in parallel with standard routers.

Two things make multicasting feasible on a global scale: the installation of high-bandwidth Internet backbone connections and the widespread availability of workstations with adequate processing power and built-in audio capability.

Multicast provides one-to-many, several-to-many, and many-to-many network delivery services. An example of a one-to-many service is the live transmission of a technical conference. A several-to-many service might be a panel interview among different locations attended by dispersed sets of people. A many-to-many service might be a distributed research exercise with 100 active contributors. Multicast is useful for a variety of videoconferencing, audio, and multiplayer events in which numerous hosts must communicate simultaneously.

Multicast currently uses only the User Datagram Protocol (UDP) and not the Transmisssion Control Protocol (TCP) of the Internet Protocol (IP) suite. Therefore, multicast streams are a connectionless, "unreliable" service: Lost MBone packets stay lost. This "best-effort" service requires no setup, uses no acknowledgments, and guarantees no delivery. Ordinarily, this is a good thing for most real-time information streams (such as audio and video) because it avoids delivery bottlenecks and unwanted overhead. However, this can pose difficulties for future development of collaborative 3D large-scale virtual worlds. Recently, Web tool developers have also begun to address incorporating desktop videoconferencing capabilities into Web browsers. A more carefully engineered backbone service that includes dedicated multicast capabilities, dedicated bandwidth, and dedicated latency is needed to support the future development of Web-based, 3D, large-scale virtual worlds.

VRML techniques have also recently been applied to visualizing the complexity of MBone virtual networks and Internetworked Graphics roadblocks (T. Munzner et al., "Visualizing the Global Topology of the Mbone," *Proc. IEEE Symp. Information Visualization*, IEEE CS Press, 1996). Information visualization techniques will aid the future development of telecommunications technology.

BOTTLENECKS AND ROADBLOCKS

The development of the next generation of Web software requires effective implementation of these Internetworked Graphics concepts. Those who develop networking protocols and MBone capabilities must factor in the impact that VRML and interactive visualization will have on future bandwidth and latency. Those who create Web-based interactive graphics tools must understand the underlying networking standards and infrastructure in order to build effective 3D collaborative applications. Without an integrated approach, bottlenecks and roadblocks will increase.

The evolution of commodity 3D computer graphics and visualization applications for PCs could present one roadblock. These applications depend on 3D graphics libraries for rendering and displaying images, and they accomplish real-time image display via accelerator cards or (potentially slower) software renderers. Developers who use these tools to create interactive 3D renderings and images to enable, for example, real-time data mining on the Internet will have to understand telecommunication bandwidth and protocols.

A key contribution of research in this area would be development tools, protocols, and algorithms that abstract away the complexity of Internetworked Graphics. These tools would provide mechanisms for effectively managing bandwidth, latency, and reliability automatically, depending on the developer's intent.

PERSONAL ASPECTS

The positive personal aspects associated with Internetworked Graphics will center on the ability to participate in real-time collaborative information discovery and visual exploration among geographically remote users.

The negative aspects will be associated with future Web development efforts. Setting up and learning to use the networking and Web infrastructure can be all-consuming and thus refocus the basic information sharing and education process. Also, the display capabilities of desktop PCs and workstations differ significantly. Even with the best networking infrastructure, some VRML worlds experienced through low-end computers will not have the intended interactivity or display characteristics. These difficulties will ultimately cause discomfort and frustration for Internetworked Graphics content developers and users. Only with an interchange between the networking and graphics communities of developers can we achieve potential reduction in these Web bottlenecks and roadblocks.

We are presently developing tutorials that teach the networking community about 3D computer graphics and the graphics community about telecommunications issues (http://siggraph.org/~rhyne/com97/com97-tut.html).

We have also developed proposals for a virtual reality transfer protocol (http://www.stl.nps.navy.mil/~brutzman/vrtp/). VRTP is intended to be public-domain software that will provide any desktop computer with client, server, peer-to-peer, and network monitoring capabilities. People will use VRTP with 3D Internet browsers to navigate and join large, interactive, fully internetworked computer graphics environments. ❖

Theresa-Marie Rhyne is a lead scientific visualization researcher for Lockheed Martin at the United States Environmental Protection Agency's Scientific Visualization Center; contact her at trhyne@vislab.epa.gov.

Don Brutzman is an assistant professor in applied science at the Naval Postgraduate School; contact him at brutzman@nps.navy.mil.

Michael Macedonia is vice president in charge of developing global virtual environments at Fraunhofer Center for Research in Computer Graphics, Inc.; contact him at mmacedon@crcg.edu.